An Ultra Modern Shortwave Radio

A simple circuit, a USB TV tuner, your computer, and some powerful software combine to make an amazing software defined communications receiver.

By George R. Steber

This unusual radio can be used to receive conventional amplitude modulation (AM) and frequency modulated (FM) stations, as well as more specialized modes such as narrow band FM (NFM), single-side band (SSB), continuous wave (CW), and other signals. Its performance — while good — is slightly below the best shortwave listening (SWL) receivers or ham radios. However, we will show you how to improve its performance substantially with tunable filters.

As it stands, it does a creditable job in many situations and has features that many other radios do not — like digital signal processing, spectrum analysis, and a waterfall display. As an added bonus, you will be able to receive frequencies from 24-1766 MHz in case you tire of the classic shortwave frequencies.

In today's jargon, this receiver would be called a software-defined radio (SDR) — a concept made popular by the military. Typically, in an SDR receiver, an analog-to-digital conversion (ADC) is made on the RF signal, and the rest of the functions of a classic analog receiver are performed on the digital signals in software. These functions include tuning, filtering, and demodulation. Using software to replace hardware allows more versatility, provides more functions, and reduces hardware complexity.

For this design, we will use a simple RF converter and a small inexpensive commercial digital TV module to provide the up-front hardware. The rest of the functions will be done on the computer.

So, if you want to explore the world of shortwave radio and learn more about this technology, read on and definitely consider building your own software-defined receiver.

Software-Defined SW Receiver

Figure 1 is a block diagram of our shortwave SDR receiver. Starting from the antenna, there is an RF converter/mixer block. The purpose of this block is to perform frequency up-conversion of the shortwave signals. This is necessary because the next block requires RF signals above 24 MHz. Therefore, a simple up-conversion of the signals is performed using a mixer. Also in this block are some analog filters to prevent strong AM and FM signals from overloading the mixer and causing intermodulation distortion.

The next block is a digital TV tuner — an amazing device that does most of the work. It is connected to the RF up-converter with a short coaxial cable to its antenna terminal. In this device, analog signals from the up-converter are tuned, changed to digital signals, and conveyed via USB to the last block.

The final block is your home PC which performs all the necessary digital signal processing. It should be

It was the simplest of times — it was the most complex of times. Indeed, much like those words, this shortwave radio project is probably the simplest, most complex one you have ever seen. It is simple because the main hardware components are low cost, readily available, and easy to assemble. It is complex because you need to download and install a special USB driver and other software on your PC — and get it all working together. Once the components are assembled and the software is installed, however, you will have a very versatile shortwave radio that covers the 1-30 MHz range, and provides many enjoyable hours of shortwave listening and experimentation. Since the software is free and the components are cheap, you should be able to build this receiver for around $25.

moderately fast, have some USB ports, and a sound card. The input data to the computer is entirely in digital form, coming from the TV tuner via USB. After applying digital algorithms for filtering and demodulation in the PC, the processed digital data is presented to the sound card — all in the digital domain. Finally, the sound card is used to convert the digital data to audio to drive speakers or headphones. Before we continue with details of the design, let's take a closer look at the little tuner device that makes this project possible.

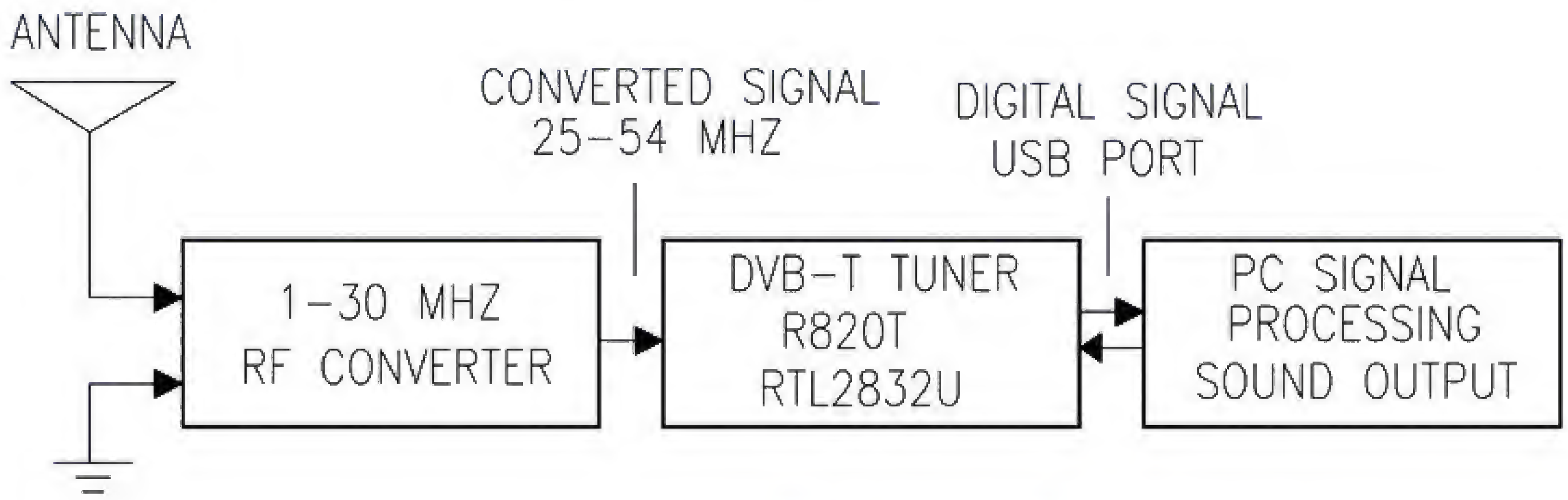

FIGURE 1. Block diagram of SDR SW receiver.

Mini DVB-T USB Tuner

The digital terrestrial TV age is in full bloom for millions of viewers around the world — especially in Europe. Analog terrestrial TV has been replaced by the new Digital Video Broadcasting Terrestrial (DVB-T) standard in many places. Viewers use mobile USB TV tuners with their computers for reception of HDTV broadcasts. Mobile tuners have compact dimensions — about the size of a memory stick. They plug into and are powered by the USB 2.0 port of your computer.

Figure 2 is a photo of a DVB-T tuner package purchased on eBay for about $11 (including shipping). As you can see, a remote control and an antenna are included — ideal for watching TV on your laptop.

We will not be using the DVB-T tuner for TV viewing in this project. Besides, it would not work in the US since the DVB-T standard is not implemented here. Instead, it will be repurposed to act as a wide-band tunable SDR receiver. Hence, we will not need the other items in the TV package.

FIGURE 2. Low cost DVB-T package.

Post comments on this article and find any associated files and/or downloads at www.nutsvolts.com/index.php?/magazine/article/july2015_Steber.

FIGURE 3. RTL tuner (with R820T and Realtek RTL2832U inside) and BNC adapter cable.

Figure 3 is a photo of the DVB-T stick we are using and a short interface cable that was bought separately. Most DVB-T sticks have two main chips inside: a digitally controlled tuner and an ADC that samples the baseband signal and outputs the samples to a host computer through a USB port.

A *very specific* DVB-T stick is used in this project — one that has a Rafael Micro R820T tuner IC and a Realtek RTL2832U inside. These so-called RTL sticks are quite common and available from many sources. Beware, though, as some sticks have an E4000 tuner or some other kind of tuner IC inside. Those *will not* work in this project. Make sure your stick has an R820T inside.

The R820T tuner is crucial because it has the lowest tuning range — tunable down to 24 MHz. Other tuners do not have that low-end range. As we will see later on, this capability makes our shortwave up-converter easy to build.

What makes the RTL stick so valuable is its inherent ability to demodulate FM signals and transfer the amplitude and phase information as raw in-phase and quadrature phase (I/Q) samples to the computer via USB. Annti Palosaari — a Finnish engineering student and Linux developer — discovered this special radio mode. Amazingly, this mode enables the tuner to output a stream of eight-bit I/Q samples at rates up to two million samples per second.

Once this discovery was grasped, enthusiasm grew for the development of a cheap SDR. The group from Open Source Mobile Communication (Osmocom) — particularly Steve Markgraf — developed a basic set of drivers and utilities to communicate with the RTL dongle. After that, other software developers began writing code to use these drivers and provide user interfaces. One of those programs, SDR# (pronounced SDR Sharp) is probably the most popular one. We'll discuss it in more detail later on.

RF Converter and Assembly Details

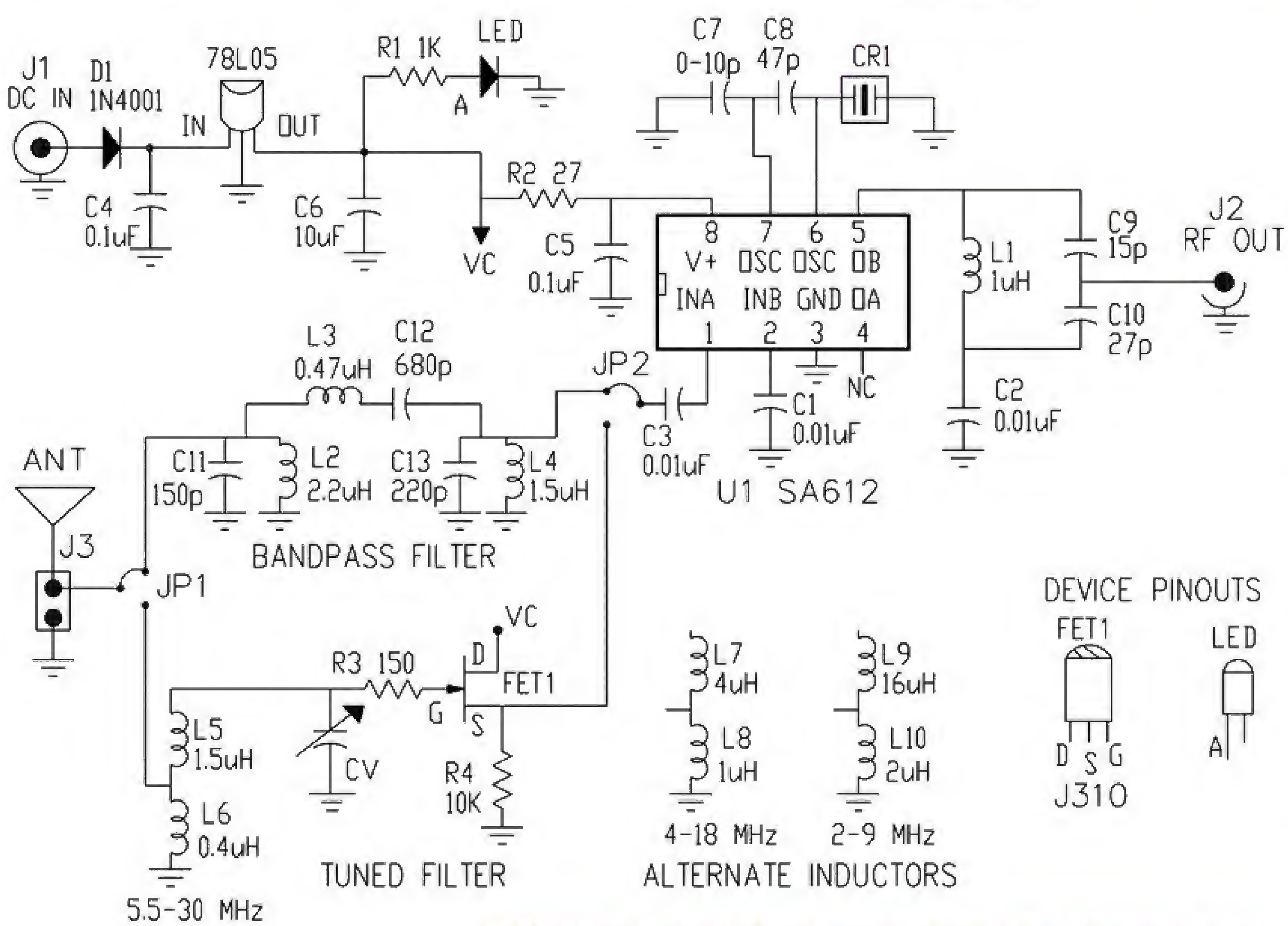

FIGURE 4. Detailed schematic — shortwave radio RF up-converter.

The front end of our shortwave receiver is a frequency up-converter. An up-converter is a circuit that adds a constant frequency to the received frequency — the one received at the antenna. An RF mixer and local oscillator can be used to make a simple up-converter. If we use a local oscillator frequency of 24 MHz, then the output of the mixer will contain the received signal plus 24 MHz. Both the local oscillator and the mixer functions can be handled by a general-purpose SA612 device.

If you search the Internet, you will see some designs that use

down-converters with 125 MHz local oscillators. These circuits are overly complicated and harder to build. They are also more prone to spurious signals and more costly. Our little up-converter costs quite a bit less and performs better in most instances.

The design of the frequency converter is straightforward. However, there is one slight wrinkle as two different front-end filters are presented: broadband and tunable. This gives diverse users the option to utilize the SDR for different applications. The broadband filter is low cost and works well over the entire 1.5-30 MHz range, but has more noise due to intermodulation from strong in-band stations. This option works well for strong AM SW stations from around the world without the bother of peaking a filter.

On the other hand, the tunable filter has a narrower band and requires manual signal peaking, but has less noise and can dig out the weak stations. This option is better for receiving amateur radio and other low power stations.

Figure 4 is the circuit for the 24 MHz up-converter. A parts list for the project is shown in **Figure 5**. Most parts for the receiver are readily available from sources like Mouser, Digi-Key, and Jameco. The SA612 is the only chip in the circuit, and is used for mixing and local oscillator functions. The up-converter frequency is determined by crystal CR1. It needs to be 24 MHz or slightly higher. The exact frequency is not critical, as an offset frequency will be used in the final software to compensate. So, any frequency in the range of 24 MHz-24.6 MHz will work fine. It is important that the capacitors C7 and C8 be good quality — like Class 1 NPO ceramic or even silvered mica — to minimize temperature drift. C7 is probably not needed. Leave it out if the circuit oscillates without it.

The circuit is powered from eight to 12 volts DC and is regulated via the 78L05. Use a linear voltage supply as opposed to a switching type to avoid noise. Batteries work well too, as the current draw is small.

As mentioned earlier, there are two RF input filter choices. Choosing the upper jumpers on JP1 and JP2 connects the bandpass filter (BP). You don't actually need to build both filters — only build the one you want. The BP filter is designed to remove strong stations from the AM broadcast band and FM band that would otherwise overload the mixer.

The other choice is the tuned filter. It requires hand wound high Q coils and a variable capacitor to peak the signal. (See the Parts List for details.) For this filter, only specific bands are covered. So, with this option, if you want to cover the whole HF range, you will need to provide switching between coils. The improved performance may be worth it.

The variable capacitor CV needs to have a wide range — typically 15 pF to 400 pF. These capacitors are getting more expensive and harder to find, but can still be found on the Internet for around $15.

The output "up-converted" signal is provided to J2 (BNC) through a tuned output stage designed to match the 75 ohm input of the RTL antenna. **Figure 6** is a breadboard for the tuned filter receiver. In general, this open layout is not recommended for RF circuits. For best performance, the mixer circuit should be built on a PCB (printed circuit board) and housed in a small metal box. Although a PCB design is not available, it should be easy to make — even for beginners.

A short coaxial cable is connected from J2 to the RTL stick's antenna terminal. The RTL usually has an MCX type connector as its antenna terminal. Because an MCX plug is very small and difficult to solder, it is suggested that you buy a ready-made adapter cable — an MCX plug with a short RG316 cable to BNC. **Figure 3** shows such an adapter cable. To reduce computer noise, a USB

Parts List

Qty	Label-Value	Designation(s)	Description
3	0.01 µF	C1, C2, C3	Mono capacitor
2	0.1 µF	C4, C5	Mono capacitor
1	10 µF	C6	Electrolytic
1	0-10 pF	C7	Class 1 NPO ceramic- see text
1	47 pF	C8	Class 1 NPO ceramic
1	15 pF	C9	Ceramic capacitor
1	27 pF	C10	Ceramic capacitor
1	150 pF	C11	Ceramic capacitor
1	680 pF	C12	Ceramic capacitor
1	220 pF	C13	Ceramic capacitor
1	1K	R1	1/4W 5% resistor
1	27	R2	1/4W 5% resistor
1	150	R3	1/4W 5% resistor
1	10K	R4	1/4W 5% resistor
1	1 µH	L1	Fastran RF inductor, Mouser
1	2.2 µH	L2	Fastran RF inductor, Mouser
1	0.47 µH	L3	Fastran RF inductor, Mouser
1	1.5 µH	L4	Fastran RF inductor, Mouser
1	1.5 µH	L5	15T, T50-6 core
1	0.4 µH	L6	9T, T50-6 core
1	4 µH	L7	28T, T68-6 core
1	1 µH	L8	13T, T50-6 core
1	16 µH	L9	56T, T68-6 core
1	2 µH	L10	20T, T50-6 core
1	78L05	78L05	5V regulator, Jameco
1	J310	FET1	FET
1	LED	Green	LED
1	15-400 pF	CV	Variable capacitor
1	J1	DC	Jack 3.5 mm
1	J2	RF OUT	BNC type
1	J3	ANT	Two terminal
1	U1	SA612	RF mixer/osc, Mouser
1	D1	1N4001	Diode
1	CR1	Crystal	24 MHz - see text

Figure 5. Parts List for SDR SW receiver.

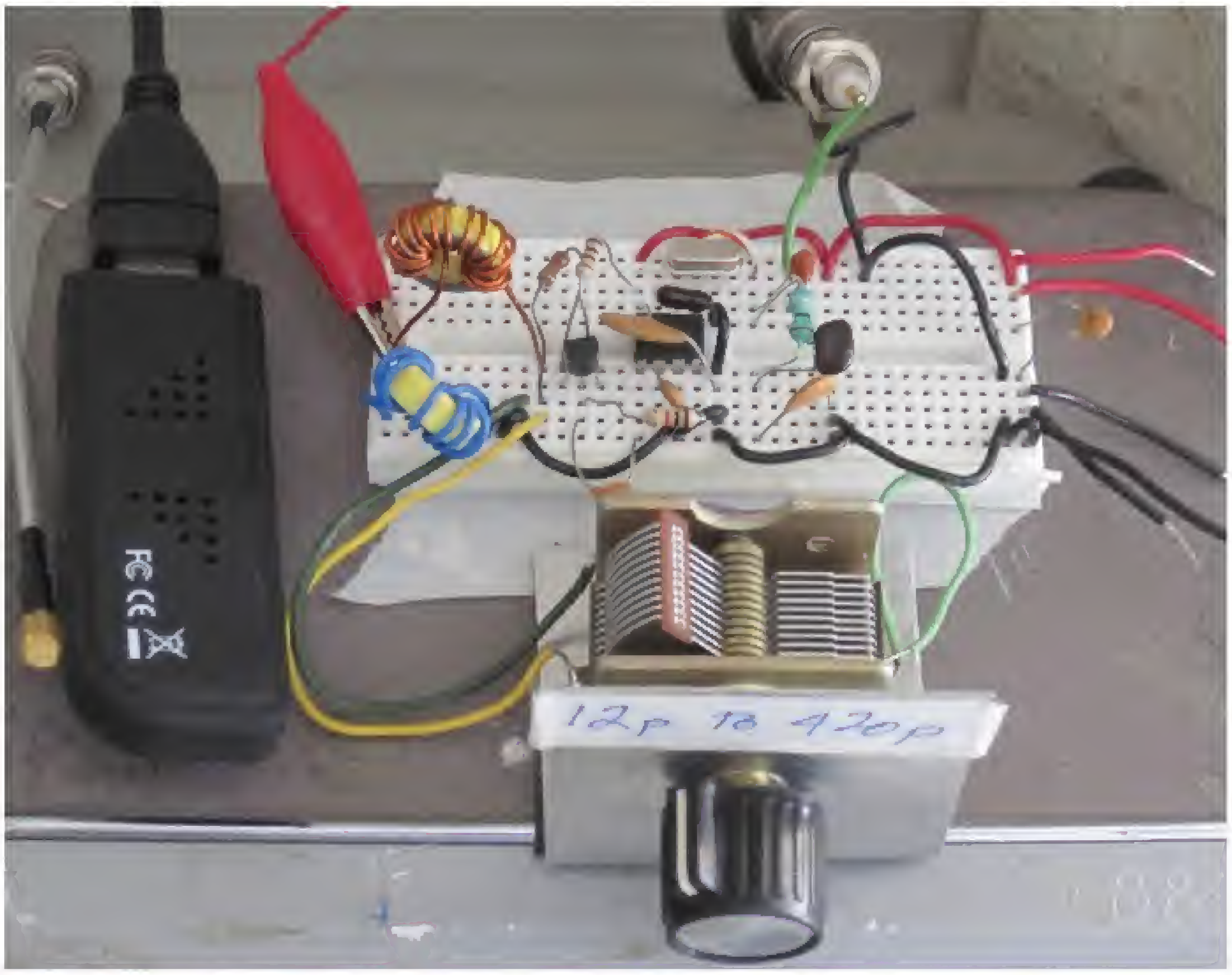

FIGURE 6. Breadboard of tunable filter shortwave radio.

waterfall plot. Running SDR# is like having a radio lab at your disposal. More details on its operation can be found at **http://sdrsharp.com**.

Now, let's take a look at some of the screen buttons. In the upper left corner is the Play button — which obviously starts the program. What is not obvious is that some settings cannot be changed while it is running. So, if you cannot set something, make sure the program is stopped. The first thing you should do is select the USB driver you installed by pressing the down arrow located next to the Play button. Choose RTL-SDR/USB from the available options.

Next, click Configure. Choose a sample rate of 1.024 MSPS and Quadrature sampling. Leave the other boxes blank. Notice that there is a slider to select the RF gain. Set it to about 14.4 dB. It can be changed later if it's too low. There is another box at the bottom that allows correction for the crystal frequency inside the RTL. We will discuss that later.

Now, look below the Play button. There are numerous buttons for selecting NFM, AM, and so forth. In this screen area is a box labeled Shift. Click this box and enter: 24,000,000. Notice the 'minus' sign. This number corresponds to the crystal frequency in the up-converter and will provide the first rough correction — it enables SDR# to read out the RF SW frequency directly.

Now, move down to the Audio section. The Samplerate and Input boxes should be grayed out. This is because data is being sent via USB not audio. In the Output box, select the sound card that you are using. It will produce the sound you will hear.

Let all of the other settings in SDR# be at their default for now. You will have lots of fun experimenting with them later on. Connect a long wire antenna and ground counterpoise. Make them as long as possible — 25 feet or more. With any luck, you should now have a functioning SW radio.

Three automatic gain controls (AGC) are available. The ones in the Configure box do not work well. The AGC on the main screen works well on strong stations. For weak stations, leaving AGC off and manually adjusting the RF gain may work best.

Other SDR# settings are usually a matter of preference, but here are some guidelines. Generally, a moderate value of Zoom should be used unless you are calibrating the radio. This makes it easier to click on a peak to select a station. Use a small number for FFT — typically 4096 to get good computer performance. Use a bandwidth that is appropriate for the signal being monitored: CW 800 Hz; SSB 2.8 kHz; and AM 10 kHz. A

extension cable may be used to move the RTL farther away from the computer.

Software Installation and Settings

First of all, do not use any of the software that came with your RTL device. It was designed for a different application. For our radio, the RTL stick requires a special USB driver and a graphical radio interface. You will need to install Zadig for bulk interface drivers and then SDR# for the radio interface. Once Zadig is run, you will have a new USB driver named "Bulk-In, Interface (Interface 0)." That is what the RTL device uses.

After you install SDR#, you will be able to select this driver to use with your radio. Also note that — depending on your PC operating system — you may need Microsoft's Net 3.5 for the installation to work.

The software installation discussed earlier is too detailed to present here. The following websites can take you through the procedure. Perhaps the best site that covers the entire installation is **www.rtl-sdr.com/rtl-sdr-quick-start-guide**. Other sites to check are **http://rtlsdr.org/softwarewindows** and **http://inst.eecs.berkeley.edu/~ee123/fa12/rtl_sdr.html**. The installation may seem a bit daunting when you are just starting out, but remember, once you get it working it will be well worth the effort.

A screenshot of SDR# tuned to WWV is shown in **Figure 7**. It's interesting to see atmospheric fading in the

filter order of 40 works well and will have little effect on program speed.

Tuning in an SSB station can be a challenge as there is no carrier peak. Tune to the left or right of the signal depending if USB or LSB is used, and adjust the frequency dial slowly until voice is intelligible.

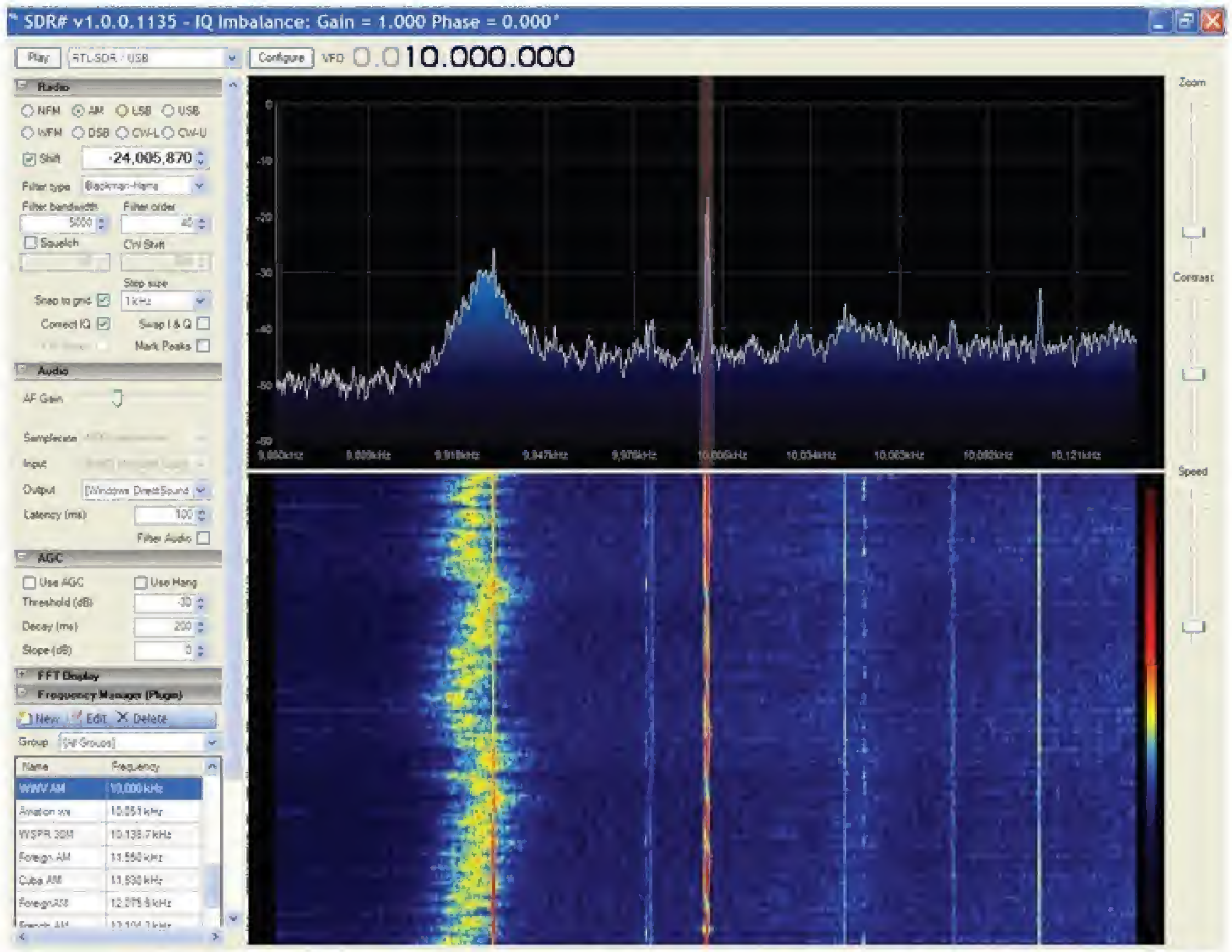

FIGURE 7. SDR# opening screen — radio tuned to 10 MHz WWV.

You may want to calibrate the frequency dial more accurately. This is a two-step procedure as there are two crystal oscillators used here: one in the RTL and one in the RF converter. To calibrate the RTL, uncheck Shift and connect a short wire of three or four feet directly to an RTL antenna terminal. This should allow you to pick up a NOAA weather station in your area — usually around 162.400 MHz. Look up exact frequencies on the Internet. Note that NOAA uses NFM. Click Configure and adjust the Frequency Correction (PPM) until the dial reading corresponds to the NOAA frequency.

To calibrate your HF SDR receiver, check Shift and tune to station WWV using USB — not AM. WWV at 10 MHz is useful for calibrating. Use a high value of FFT resolution — around 131,073 — so you can see WWV peak clearly in the spectrum. Adjust the Shift value until the dial reads the peak frequency accurately to within 50 Hz. It will drift periodically, but that is the nature of uncompensated crystal oscillators.

As noted above, if you bypass the HF converter and use an antenna directly connected to the RTL, you can take advantage of the very large frequency range of this device — up to 1,766 MHz. Thus, you may be able to directly pick up FM stations (and other stations like NOAA) and two-meter ham repeaters if they are close enough.

Final Comments

Hopefully, by now you should be having fun with your SDR SW receiver. If you are having difficulties, go to **http://sdrsharp.com** or the Yahoo SDR group and they may be able to help.

Shortwave radio is more exciting now than ever before. Many new AM broadcasters from China, Cuba, Europe, and other places will keep you informed and entertained. Religious broadcasters also abound. Unfortunately, many of the interesting stations only appear at night due to propagation conditions. Fortunately, the powerful ones come booming in even in the daytime.

Listening to ham radio operators using SSB and Morse code is also fun — especially during contests. Other stations are using SSB too, such as Maritime WX on 8.763 MHz and Aviation WX on 10.051 MHz. These generally use synthetic voices. If you are lucky — as I was — you may hear one of the mysterious 'numbers' stations using USB around 13.199 MHz. However, they are seldom in the same spot twice. Also interesting are utility stations such as WLO, which transmits on many frequencies and provides high seas communication and weather information.

One of the exciting things you can do with this radio is receive data transmissions such as WX FAX, SITOR, RTTY, BPSK, WSPR, and EasyPal SSTV. These modes can easily be decoded with available software, but to discuss this further would require another magazine article!

If you like playing around with this radio and find the subject fascinating, you may want to consider becoming a radio amateur. Hams are involved with building and studying receivers, transmitters, antennas, satellites, EME, microwaves, and experimenting with new radio modes such as WSPR, BPSK, Packet Radio, and more. If you are considering joining the fraternity of radio amateurs, the ARRL website may be the place to start. Be sure to check out the new column here in *Nuts & Volts*, as well.

In the meantime, have fun with your new SW radio. **NV**